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Riddering et al.

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(54) **DETERMINING GAMMA OF A READ/WRITE HEAD BASED ON ACTIVE GAIN CONTROL AND TEST SIGNAL AMPLITUDE MEASUREMENTS**

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G11B 5/012	(2006.01)
G11B 20/10	(2006.01)
G11B 5/00	(2006.01)
G11B 5/48	(2006.01)
G11B 19/04	(2006.01)

(52) **U.S. Cl.**
CPC ***G11B 5/6029*** (2013.01); ***G11B 5/6011*** (2013.01); ***G11B 20/10314*** (2013.01); ***G11B 20/10388*** (2013.01); *G11B 5/012* (2013.01); *G11B 5/4866* (2013.01); *G11B 5/6088* (2013.01); *G11B 19/046* (2013.01); *G11B 2005/0021* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,310,194	B1 *	12/2007	Schardt	G11B 5/3133 360/75
9,001,451	B1	4/2015	Martin et al.	
2014/0269819	A1	9/2014	Kiely et al.	

* cited by examiner

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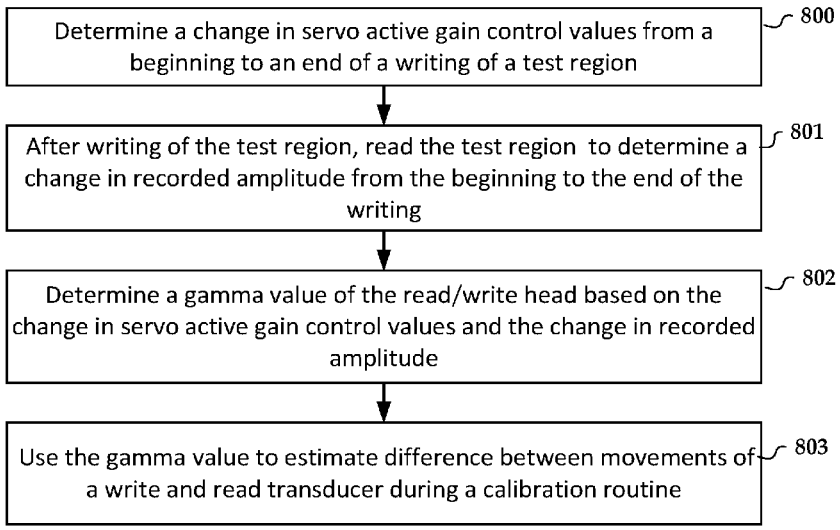
(57) **ABSTRACT**

A change in servo active gain control values is determined from a beginning of a writing of a test region of a recording medium to an end of the writing of the test region. The servo active gain control values are read from servo marks by a read transducer of a read/write head during the writing. After writing of the test region, the test region is read by the read transducer to determine a change in recorded amplitude from the beginning of the writing to the end of the writing. A gamma value of the read/write head is determined based on the change in servo active gain control values and the change in recorded amplitude.

20 Claims, 5 Drawing Sheets



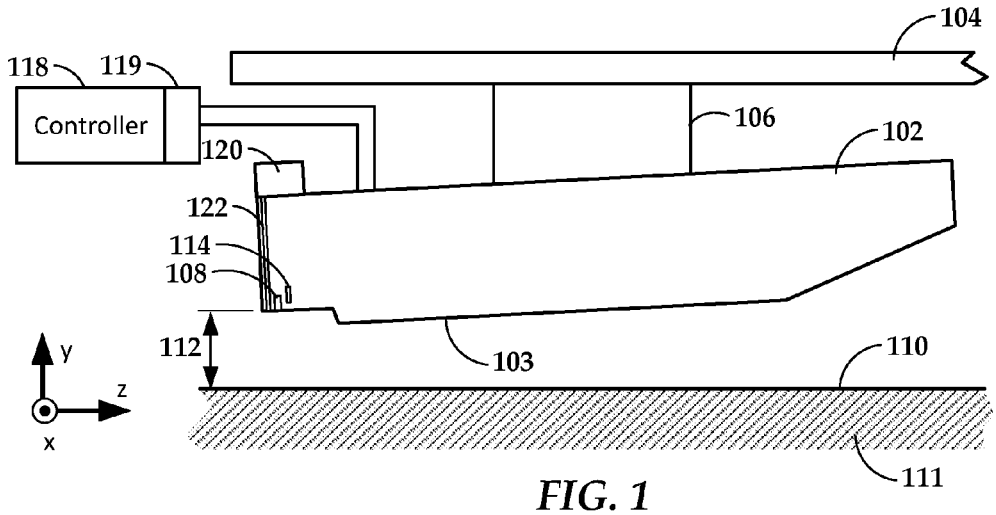

104
118
119
Controller
120
106
102
122
114
108
112
103
110
111
y
z
x

FIG. 1

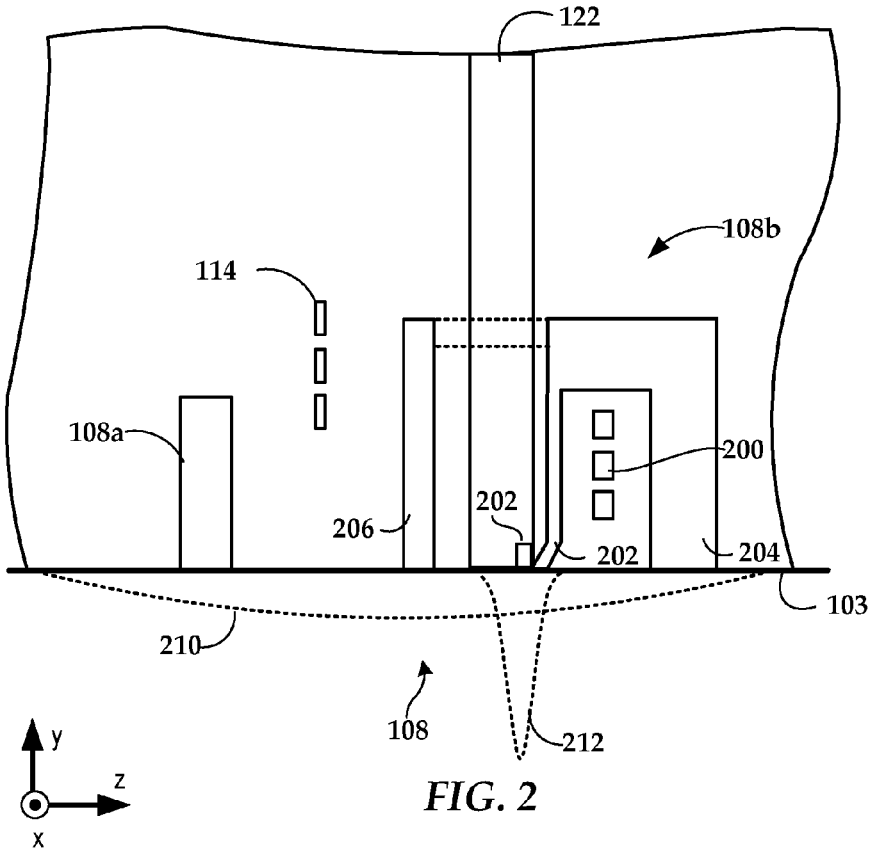

122
108b
114
108a
200
206
202
202
204
103
210
108
212
y
z
x

FIG. 2

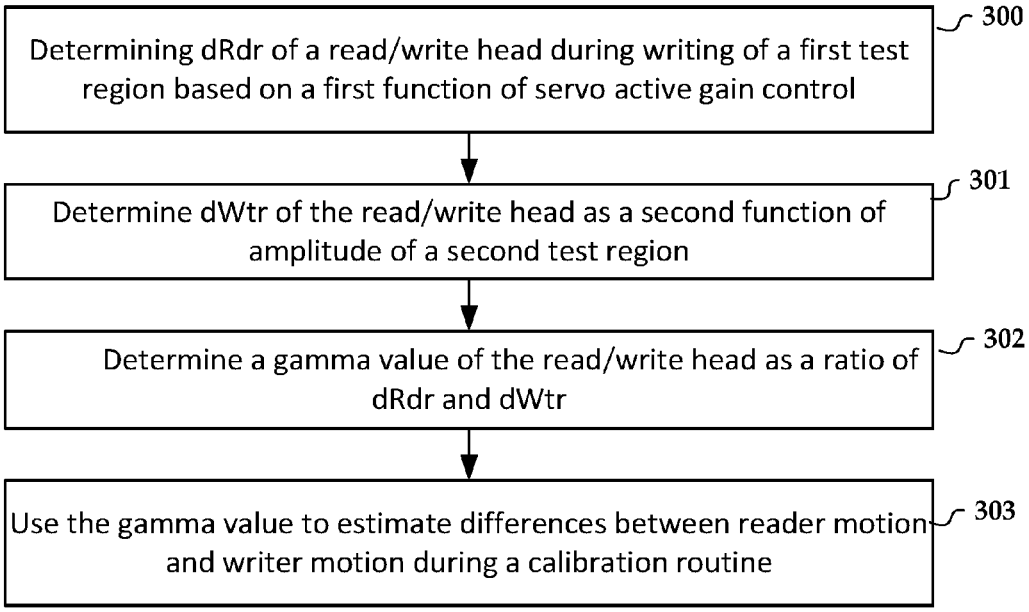

Determining dRdr of a read/write head during writing of a first test region based on a first function of servo active gain control
300
Determine dWtr of the read/write head as a second function of amplitude of a second test region
301
Determine a gamma value of the read/write head as a ratio of dRdr and dWtr
302
Use the gamma value to estimate differences between reader motion and writer motion during a calibration routine
303

FIG. 3

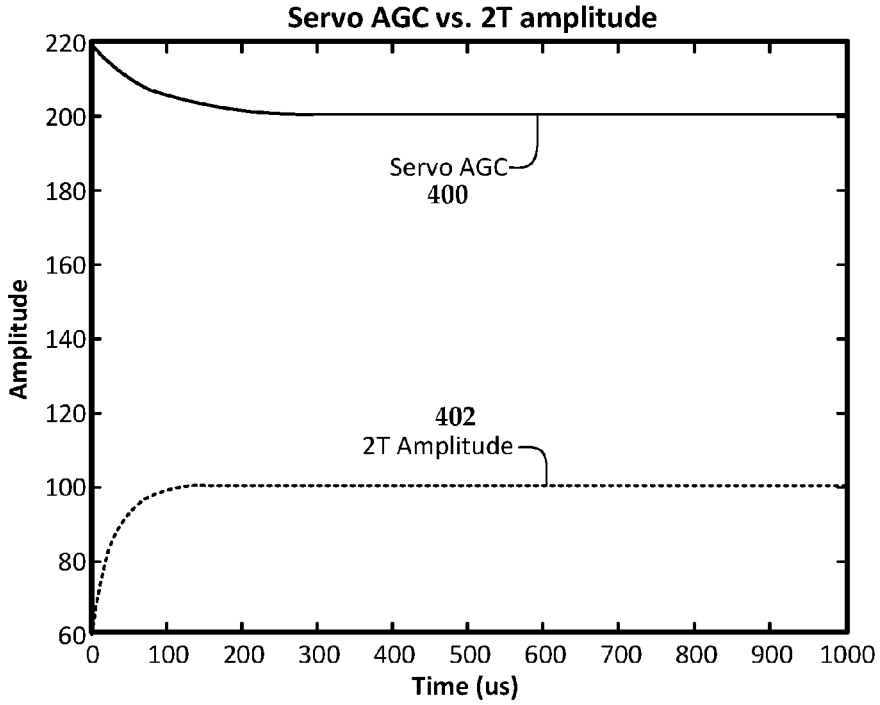

Servo AGC vs. 2T amplitude
Amplitude
220
200
180
160
140
120
100
80
60
Servo AGC
400
402
2T Amplitude
0
100
200
300
400
500
600
700
800
900
1000
Time (us)

FIG. 4

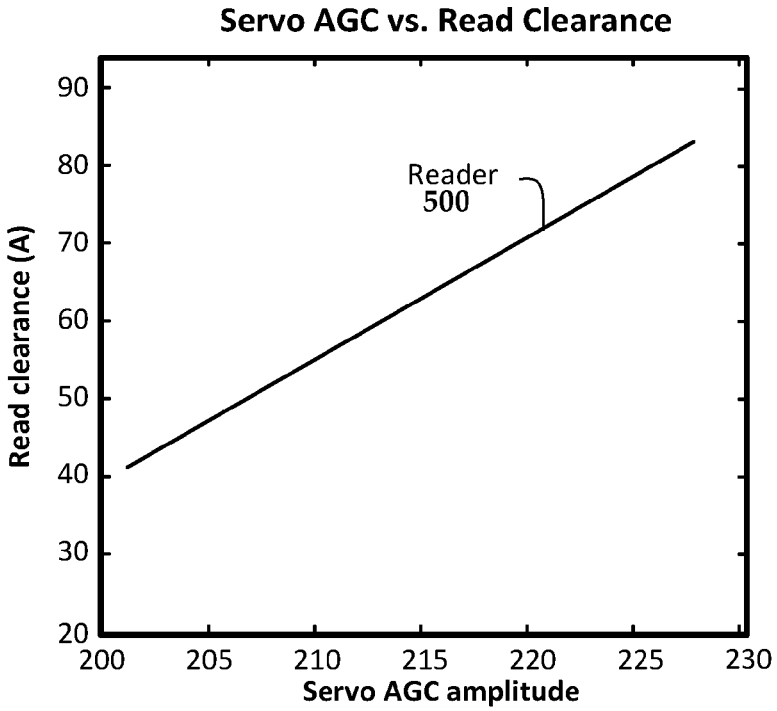

Servo AGC vs. Read Clearance
Read clearance (A)
90
80
70
60
50
40
30
20
200
205
210
215
220
225
230
Servo AGC amplitude
Reader
500

FIG. 5

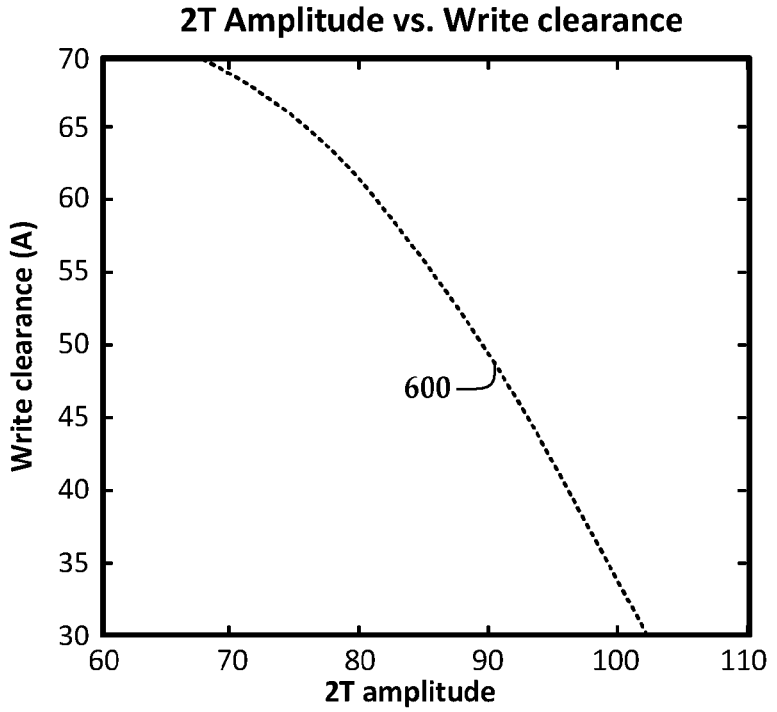

2T Amplitude vs. Write clearance
Write clearance (A)
70
65
60
55
50
45
40
35
30
60
70
80
90
100
110
2T amplitude
600

FIG. 6

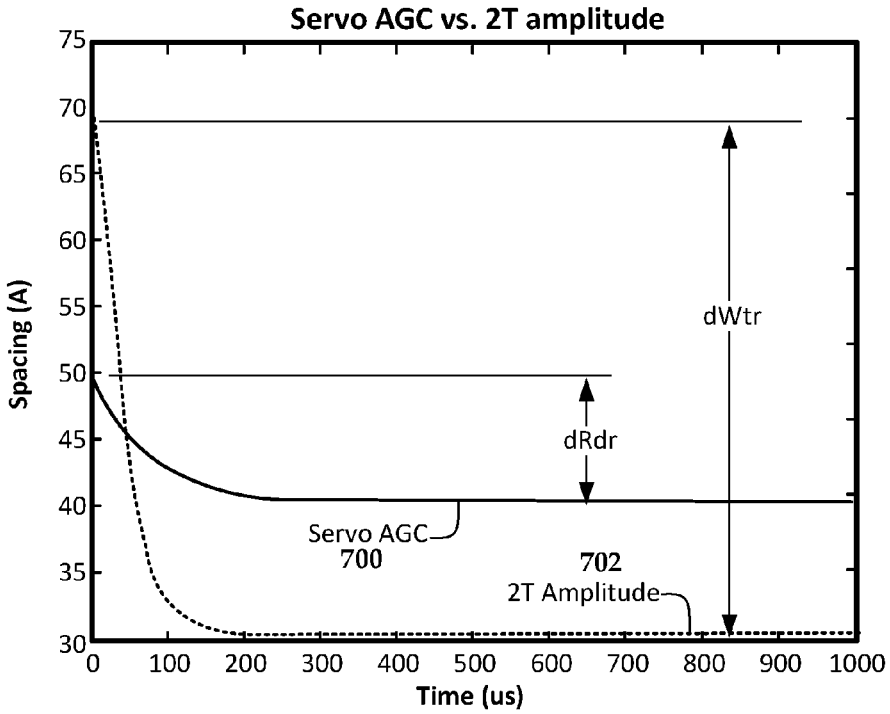

Servo AGC vs. 2T amplitude
Spacing (A)
75
70
65
60
55
50
45
40
35
30
0
100
200
300
400
500
600
700
800
900
1000
Time (us)
dWtr
dRdr
Servo AGC
700
702
2T Amplitude

FIG. 7

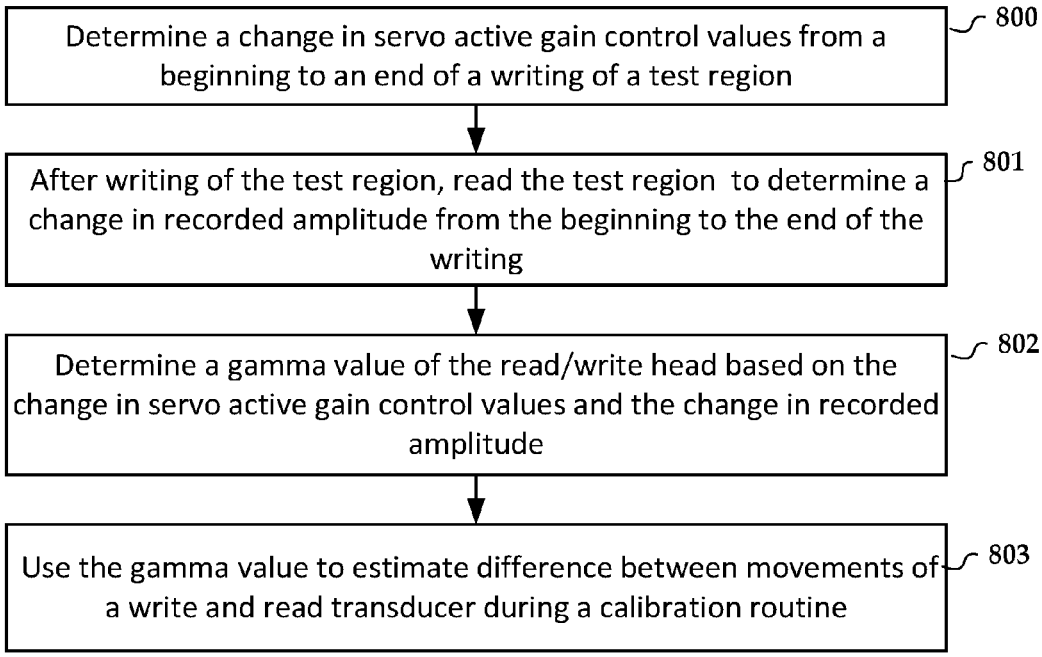

Determine a change in servo active gain control values from a beginning to an end of a writing of a test region
800
After writing of the test region, read the test region to determine a change in recorded amplitude from the beginning to the end of the writing
801
Determine a gamma value of the read/write head based on the change in servo active gain control values and the change in recorded amplitude
802
Use the gamma value to estimate difference between movements of a write and read transducer during a calibration routine
803

FIG. 8

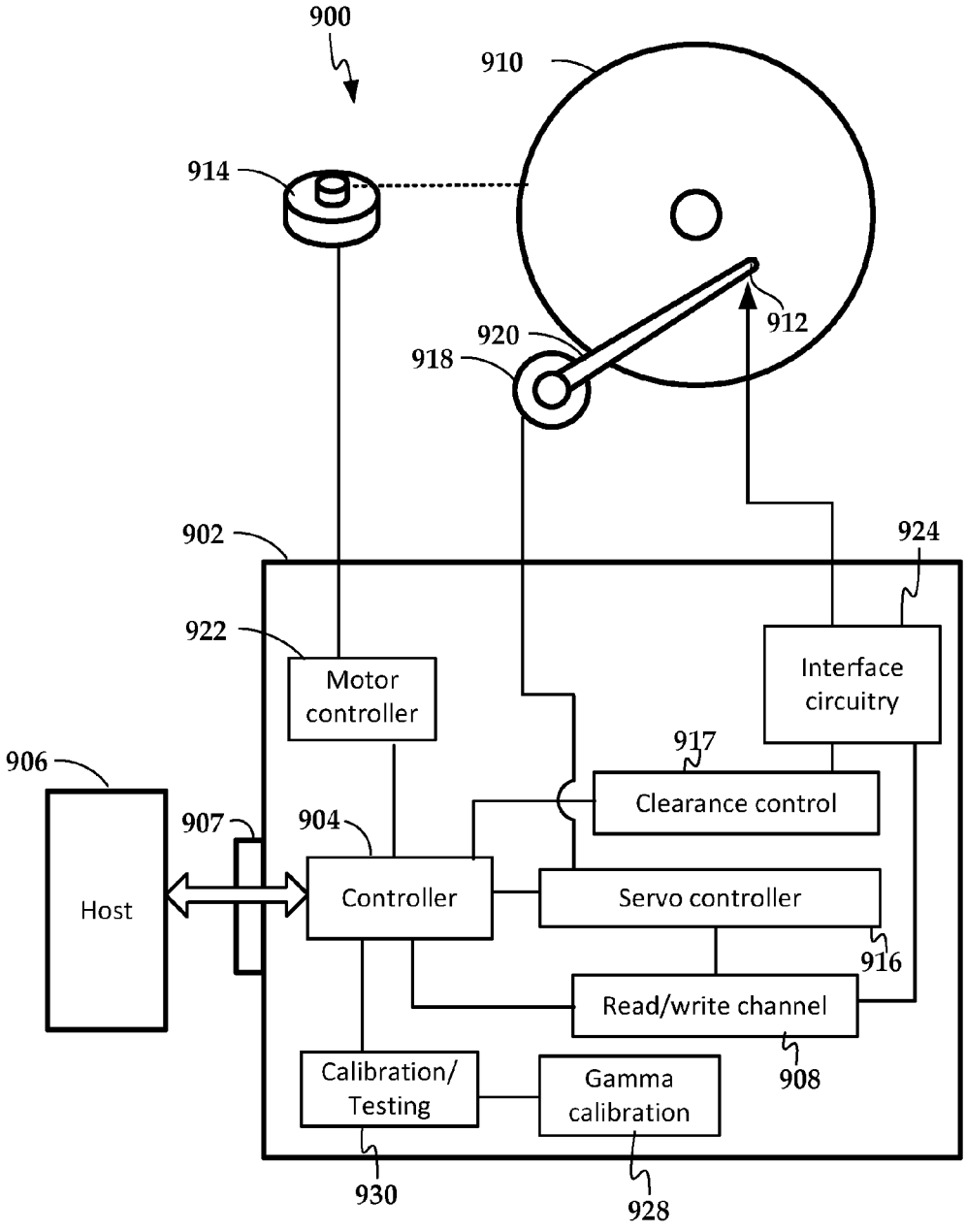

900
910
914
912
920
918
902
924
922
Motor controller
Interface circuitry
917
906
Clearance control
907
904
Host
Controller
Servo controller
916
Read/write channel
908
Calibration/ Testing
Gamma calibration
930
928

FIG. 9

DETERMINING GAMMA OF A READ/WRITE HEAD BASED ON ACTIVE GAIN CONTROL AND TEST SIGNAL AMPLITUDE MEASUREMENTS

SUMMARY

The present disclosure is directed to determining gamma of a read/write head based on active gain control and test signal amplitude measurements. In one embodiment, a change in servo active gain control values is determined from a beginning of a writing of a test region of a recording medium to an end of the writing of the test region. The servo active gain control values are read from servo marks by a read transducer of a read/write head during the writing. After writing of the test region, the test region is read by the read transducer to determine a change in recorded amplitude from the beginning of the writing to the end of the writing. A gamma value of the read/write head is determined based on the change in servo active gain control values and the change in recorded amplitude. The gamma value is used to estimate differences between a reader motion and a writer motion during a calibration routine.

These and other features and aspects of various embodiments may be understood in view of the following detailed discussion and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The discussion below makes reference to the following figures, wherein the same reference number may be used to identify the similar/same component in multiple figures.

FIG. **1** is a block diagram of a hard disk drive slider and media arrangement according to an example embodiment;

FIG. **2** is a cross-sectional view of a read/write head according to an example embodiment;

FIG. **3** is a flowchart of a method according to an example embodiment

FIGS. **4**, **5**, **6**, and **7** are graphs showing measurement of clearance data according to example embodiments;

FIG. **8** is a flowchart of a method according to an example embodiment; and

FIG. **9** is a block diagram of an apparatus and system according to an example embodiment.

DETAILED DESCRIPTION

The present disclosure generally relates to data storage devices that utilize magnetic storage media, e.g., disks. In some embodiments below, the devices use heat-assisted magnetic recording (HAMR), also referred to as energy-assisted magnetic recording (EAMR), thermally-assisted magnetic recording (TAMR), and thermally-assisted recording (TAR). This technology uses an energy source such as a laser to create a small hotspot on a magnetic disk during recording. The heat lowers magnetic coercivity at the hotspot, allowing a write transducer to change magnetic orientation, after which the hotspot is allowed to rapidly cool. Due to the relatively high coercivity of the medium after cooling, the data is less susceptible to data errors due to thermally-induced, random fluctuation of magnetic orientation known as the paramagnetic effect.

A laser or other energy source may be directly (e.g., surface-attached) or indirectly (e.g., via optical fiber) coupled to a HAMR read/write head. An optical path (e.g., waveguide) is integrated into the read/write head and delivers the light to a media-facing surface of the read/write head.

Because the size of the desired hotspot (e.g., 50 nm or less) is smaller than half a wavelength of the laser light (e.g., 800-1550 nm), conventional optical focusers (e.g., lenses) are diffraction limited and cannot be used to focus the light to create the hotspot. Instead, a near-field transducer (NFT) is employed to direct energy out of the read/write head. The NFT may also be referred to as a plasmonic transducer, plasmonic antenna, near-field antenna, nano-disk, nano-patch, nano-rod, etc.

Generally, the NFT is formed by depositing a thin-film of material such as gold, silver, copper, etc., near an integrated optics waveguide or some other delivery system. When exposed to laser light that is delivered via the waveguide, the light generates a surface plasmon field on the NFT. The NFT is shaped such that the surface plasmons are directed out of a surface of the write head onto a magnetic recording medium.

Due to the intensity of the laser light and the small size of the NFT, the NFT and surrounding material are subject to a significant rise in temperature during writing. This can affect the clearances between the read/write head and the recording medium, sometimes referred to as fly height or head-to-media spacing (HMS). Generally, localized heating will result in a region surrounding the NFT to protrude even more than the surrounding components while writing. This is sometimes referred to as laser-induced write protrusion (LIWP). This protrusion results in a decrease in clearance between the NFT (and surrounding components) and the recording medium, and is generally not directly measurable in a production drive.

Many read/write heads utilize an embedded heater (e.g., resistive heater) to induce thermal protrusion in order to control HMS. A single heater may be used for both read and write operations, or separate heaters may be used for read and write operations, respectively. The amount of current applied to the heater may be determined based on an open-loop and/or closed loop controller. Because the above-described LIWP contributes affects clearance during writing, control systems need to account for this when switching between read and write modes.

A control system may utilize what is described herein as laser gamma to set write clearances. Laser gamma (also referred to herein as NFT/Writer gamma, or just gamma) is the ratio between change in reader clearance and change in writer clearance as the head comes into thermal equilibrium during the respective operations. Generally, gamma=$\Delta W/\Delta R$, where ΔW and ΔR represent the respective change in writer and reader clearance between the start of a write/read operation at ambient temperature and a time during the write/read operations when the head has reached thermal equilibrium. Gamma is used to estimate the delta between reader motion and writer/NFT motion (e.g., reader and writer clearances) during clearance calibration routines. In embodiments described below, methods and apparatuses are described that enable measuring laser gamma. This involves using measurements of active gain control (AGC) of a read preamplifier while writing data together with measurement of test signal amplitude of a test track after the track is written. Generally, a read preamplifier uses an AGC amplifier to adjust gain of the read transducer signal so that peak signal amplitudes fall within a range that facilitates optimal decoding of the data encoded in the signal. All other factors (e.g., state of the read transducer, magnetic flux of the recorded track) being equal, relatively high levels of AGC while reading back data generally indicates relatively high clearance. Similarly, the amplitude of a test track will be higher if the written at a lower clearance, all other factors

(e.g., state of the read transducer, read clearance) being equal. As such, these values can be used to estimate both reader and writer clearances/clearance changes, and thereby estimate laser gamma.

In reference now to FIG. **1**, a block diagram shows a side view of a read/write head **102** according to an example embodiment. The read/write head **102** may be used in a magnetic data storage device, e.g., HAMR hard disk drive. The read/write head **102** may also be referred to as a slider, write head, read head, recording head, etc. The read/write head **102** is coupled to an arm **104** by way of a suspension **106**, e.g., a gimbal. The read/write head **102** includes read/write transducers **108** at a trailing edge that are held proximate to a surface **110** of a magnetic recording medium **111**, e.g., a magnetic disk. When the read/write head **102** is located over surface **110** of recording medium **111**, a flying height **112** is maintained between the read/write head **102** and the surface **110** by a downward force of arm **104**. This downward force is counterbalanced by an air cushion that exists between the surface **110** and an air bearing surface (ABS) **103** (also referred to herein as a "media-facing surface") of the read/write head **102** when the recording medium **111** is rotating.

In order to provide control of the clearance between the read/write transducers **108** and the recording medium **111**, one or more heaters **114** are formed in the read/write head **102**. A current applied to the heater **114** induces a local protrusion which varies the clearance. The amount of current applied to the heater **114** may vary based on which of the read/write transducers **108** are in use, and may also be adjusted to account for irregularities in the media surface **110**, changes in ambient temperature, location of the read/write head **102** over the medium **111**, etc. Thermal sensors (not shown) may also be included in the read/write head **102** to facilitate measuring clearances, e.g., by measuring a thermal profile as a function of heater power.

A controller **118** is coupled to the read/write transducers **108**, as well as other components of the read/write head **102**, such as heaters **114**, sensors, etc. The controller **118** may be part of general- or special-purpose logic circuitry that controls the functions of a storage device that includes at least the read/write head **102** and recording medium **111**. The controller **118** may include or be coupled to a read/write channel **119** that include circuits such as preamplifiers, buffers, filters, digital-to-analog converters, analog-to-digital converters, decoders, encoders, etc., that facilitate electrically coupling the logic of the controller **118** to the signals used by the read/write head **102** and other components.

The illustrated read/write head **102** can be optionally configured as a HAMR device, and so includes additional components that form a hot spot on the recording medium **111** near the read/write transducer **108**. These components include a laser **120** (or other energy source) and a waveguide **122**. The waveguide **122** delivers light from the laser **120** to components near the read/write transducers **108**. These components are shown in greater detail in FIG. **2**, which is a block diagram illustrating a cross-sectional view of the read/write head **102** near the read/write transducers **108** according to an example embodiment.

A read transducer **108***a* is located downtrack from a write transducer **108***b*. The read transducer **108***a* may be configured as a magnetoresistive stack (e.g., giant magnetoresistive, tunnel magnetoresistive, etc.) surrounded by magnetic shields. The write transducer **108***b* includes a coil **200** that, when energized, induces magnetic flux through a write pole **202** and return poles **204**, **206**. The aforementioned waveguide **122** delivers light to an NFT **202** located near the write pole **202**.

The diagram of FIG. **2** shows protrusion near the read/write transducer **108** at the media-facing surface **103**. During reads and writes, the heater **114** is activated to control protrusion of the read transducer **108***a* and write transducer **108***b*, as generally indicated by broad protrusion shape **210**. The write pole **202** and other components of the magnetic writer may also heat significantly while writing, and so contribute to the broad protrusion **210** during write operations. The broad protrusion shape **210** is not necessarily to scale, other than to indicate that it is occupies a fairly broad region near the read/write transducer **108**. In contrast, the optical components such as NFT **202** and waveguide **122** cause a narrower protrusion **212**. The narrow protrusion **212** covers a smaller region than the broad protrusion **210**. This narrow protrusion **212** may also extend further away from the media-facing surface **103** than the broad protrusion **210**.

Another distinguishing feature of the narrow protrusion **212** is the time constant, e.g., the relative amount of time it takes to maintain a stable shape after application of heat via the energy source. The narrow protrusion **212** can have a thermal expansion time constant on the order of 1/10 to 1/100 of an equivalent time constant the broad protrusion **210**. Therefore the narrow protrusion **212** can react significantly faster to input from the energy source compared to the broad protrusion's response to activation of the heater **116**.

Reader protrusion can be measured directly by the read transducer **108***a*. For example, a signal level of pre-written servo data (e.g., via AGC levels used when reading servo marks) can be used to measure clearance of the read transducer. However, writer protrusion is not measured directly because the write transducer **108***b* does not have a read sensor or similar sensing capability. As a consequence, a fixed predetermined value for the reader and writer protrusion ratio (e.g., gamma) may be used to determine writer heater power. A method to find this gamma value for a HAMR read/write head is shown in the flowchart of FIG. **3**.

The method involves determining **300** a change in a reader clearance (dRdr) of a read/write head during writing of a first test region based on a first function of servo active gain control. A change in a writer clearance (dWtr) of the read/write head is determined **301** during writing of a second test region as a second function of amplitude of the second test region. The amplitude is read after the second region is written. A gamma value of the read/write head is determined **302** as a ratio of dRdr and dWtr. The gamma value is used **303** to estimate the delta between reader motion and writer/NFT motion during clearance calibration routines, e.g., during drive factory calibration. The clearance calibration routines use Wallace spacing equations (e.g., harmonic ratio) to measure the reader motion, so servo AGC-based reader spacing calibration is not needed once gamma is determined. During normal drive operation in the field (e.g., when the drive is in-use), clearance coefficients are used to set read and write clearances. These clearance coefficients can be derived using the gamma.

In FIG. **4**, a graph shows obtaining of reader and writer clearances according to an example embodiment. Curve **400** shows the determination of reader clearance during writing as a function of AGC. Curve **400** is obtained by writing a of test data, e.g. a 2T signal, to a region of the recording medium, e.g., a track. It will be understood that, while the descriptions below describe using a 2T test signal written to a track for testing, different signals (e.g., 3T, 4T) and

different regions (e.g., fractional tracks, multiple tracks) may be used alternatively or in addition.

At time <0 shown in FIG. **4**, the writer heater is set to the calibrated write heat for this head, track, write current, and laser current combination. Further, at time <0, the writer coil is off, and the laser is set to a bias current less than the laser threshold current, above which lasing will occur. At time=0, the writer heater remains constant, the writer is turned on to the optimized write triplet, and the laser current is set to the optimized laser current for this head, track, and write triplet combination. Writing of the test data commences at t≥0 with these settings. In this way, the protrusion dynamics are due only to the writer and laser turning on and reaching the target clearance.

The region of the recording medium generally includes user data sectors interleaved with servo sectors. The servo sectors include pre-written data used by the servo control system for positioning the read/write heads. The writer is turned off (e.g., by turning off the laser and/or write coil) when traversing servo sectors so as not to erase the servo data. When traversing the servo sectors, the reader is turned on to obtain the necessary data (e.g., position signals) used in positioning the read/write head over the tracks. The servo data is processed by a preamplifier, which, among other things, applies gain to the signal via the AGC before the signal is processed by a decoder. The ACG value is automatically adjusted so that its output is in a desired amplitude range that is optimal for decoding of the data.

As indicated by curve **400**, the servo AGC is returned wedge-by-wedge during the writing of the test data. As expected, the AGC value decreases over time as the write transducer components of the read/write head (e.g., optical path and write coil) come into thermal equilibrium and fully heat the nearby regions of the read/write head, which includes the read transducer. This moves the read transducer closer to the recording medium, reducing the value of ACG needed to decode servo data. As such, curve **400** represents reader spacing change during writing due to heat from the write coil and optics.

Curve **402** represents the amplitude read from a 2T test region, which may be the same region written to obtain curve **400** or a different region. After the 2T data has been written, it is traversed again by the reader and the amplitude of the 2T signal is measured. This produces curve **402**, in which the amplitude of the 2T signal is read. In this case, time=0 case corresponds to beginning of the first sector of data written during the sequence. As expected, this results in a low value of amplitude during the start of the write. This is due to the write pole and NFT being farther from the recording medium until the write transducer components of the read/write head come into thermal equilibrium and induce subsequent additional protrusion. This curve **402** represents the writer spacing change during writing due to heat from the write coil and optics. It should be noted that the curve **402** could be obtained directly by examining a signal level received at the preamplifier from the reader, or derived from AGC gain of the reader while reading the user data.

The results in FIG. **4** are in units of AGC or amplitude, which in this case are digital values provided from an analog-to-digital converter (ADC). They are representative of clearance values, and may be converted to actual clearance distance values through additional testing or known response characteristics. For example, techniques that utilize the Wallace spacing loss equation can estimate read clearance distances by examining multiple harmonics of a test signal and comparing the levels of the different harmonics. In other examples, a sensor (e.g., thermal sensor, acoustic emission sensor) can be used to estimate clearance distance based on thermal profiles and/or contact detection. These techniques can be used to map 2T amplitudes and AGC values described above to units of distance (e.g., Å).

In FIGS. **5** and **6**, graphs show clearance data obtained from separate servo AGC and 2T measurements according to an example embodiment. In FIG. **5**, a plot shows a spacing calibration for servo AGC. To obtain curve **500**, read clearance is set to a particular target value (e.g., by inputting a particular current to a reader heater/actuator) while reading servo marks during a track read. Note that read clearance setting is mostly independent of the laser and writer, and so read clearance as a function of read clearance actuator power can be reliably obtained. Average AGC (horizontal axis) is measured during a read over multiple read clearance targets (vertical axis). Curve **500** represents a curve fit of these measurements.

In FIG. **6**, a curve **600** represents a fit of and 2T amplitudes (horizontal axis) measured after writing to a test region has completed at different target clearances (vertical axis). The calculated 2T-amplitude-based clearance represents the writer/NFT clearance during the write. Note that since the laser gamma is required to set write clearance accurately, this measurement process may need to be iterative, starting with an initial guess for laser gamma, and repeated until convergence. Generally, the graphs in FIGS. **5** and **6** can be used to translate between AGC or 2T amplitude versus time and clearance distance versus time.

In FIG. **7**, a plot shows how this data can be used to determine Writer/NFT gamma. In FIG. **7**, a graph shows a change in reader clearance (curve **700**) with change in writer clearance (curve **702**) when writing a test region according to an example. As indicated in the graph, the change in reader clearance curve **700** from beginning to end of the test pattern region is dRdr and based on the AGC curve **400** combined with reader clearance versus servo AGC curve **502**. The change in writer clearance curve **702** from beginning to end of the test pattern region is dWtr and is based on the 2T amplitude curve **402** combined with 2T amplitude vs write clearance curve **600**. The ratio of the two delta clearances is the Writer/NFT gamma, e.g, Writer/NFT gamma=dWtr/dRdr. In the illustrated example, dRdr=reader start −reader end=50−40=10 A, and dWtr=writer start−writer end=70−30=40 A. As a result, Writer/NFT gamma=dWtr/dRdr=40/10=4.

After this gamma value is determined, it can be used in operation of a hard disk device. For example, when writing user data, a read clearance C_R can be determined based on servo AGC. This can be used to estimate a writer clearance C_W by using the relation C_W=gamma*C_R. This estimate can be used to control the write clearance, e.g., used to select a signal level to actuate a write heater or other clearance actuator to the desired clearance.

In FIG. **8**, a flowchart illustrates a method according to another example embodiment. The method involves determining **800** a change in servo active gain control values from a beginning of a writing of a test region of a recording medium to an end of the writing of the test region. The servo active gain control values are read from servo marks by a read transducer of a read/write head during the writing. After writing of the test region, the test region is read **801** by the read transducer to determine a change in recorded amplitude from the beginning to the end of the writing. The change in recorded amplitude may be due to thermal expansion of write components such as write coil, write pole, and laser.

A gamma value of the read/write head is determined **802** based on the change in servo active gain control values and the change in recorded amplitude. For example, a change in the clearance of the read transducer (dRdr) from the beginning to the end of the writing may be determined based on the change in servo active gain control values, and a change in the clearance of the write transducer (dWtr) from the beginning to the end of the writing may be determined based on the change in the recorded amplitude. In such a case, the gamma value is based on a ratio of dRdr and dWtr.

The gamma value is used **803** to estimate differences between a reader motion and a writer motion during a calibration routine. For example, a reader clearance during a calibration routing may be determined based on measurement of the servo active gain control during the user data writing operation. In other cases, reader clearance may be measured during the calibration routing based on Wallace loss equation measurements. In either event, the write clearance may be set based on the read clearance times the gamma value.

In reference now to FIG. **9**, a block diagram illustrates components of system **900** according to an example embodiment. The system **900** includes a HAMR hard drive apparatus **902** having one or more read/write heads **912**. The apparatus **902** includes a system controller **904** that controls a number of functions of the system **900**, such as communications between the apparatus **902** and a host device **906** via a host interface **907**. The host device **906** may include any electronic device that can be communicatively coupled to communicate with the apparatus **902**, e.g., a general-purpose computer, a factory test apparatus, remote terminal, etc.

The system controller **904** may include any combination of custom logic circuits, application specific integrated circuits (ASICs), general-purpose central processing unit (CPU), interface circuits, etc., and may utilize instructions stored as firmware and/or software. The system controller **904** may process instructions to read data from and write data to a recording medium (e.g., disk **910**) via a read/write channel **908**. The system controller **904** may, among other things, determine a location on the disk **910** for the desired data, move the heads to the location (track) of the data, read or write the data via the read/write channel **908**, correct errors, transfer the data to/from the host **906**, etc.

The read/write channel **908** converts data between the digital signals processed by the data controller **904** and the analog signals conducted through read/write heads **912**. The read/write channel **908** also provides servo data read from the disk **910** to a servo controller **916**. The servo controller **916** uses these signals to drive an actuator **918** (e.g., voice coil motor) that rotates an arm **920**, upon which the read/write heads **912** are mounted. The heads **912** are moved radially across different tracks of the disk(s) **910** by the actuator motor **918** (e.g., voice coil motor), while a spindle motor **914** rotates the disk(s) **910**. A microactuator (not shown) may also be included to provide finer tracking control, and also receives inputs from the servo controller **916**. The controller **904** controls the spindle motor **914** by way of a motor controller **922**.

During write operations, the read/write channel **908** provides analog signals that are delivered to the read/write heads **912** by way of interface circuitry **924**. The interface circuitry **924** include hardware components (preamplifiers, filters, analog-to-digital converters, digital-to-analog converters) that conditions the signals sent to and received from the read/write heads **912**. In the illustrated embodiment, the interface circuitry **924** also includes laser control circuitry that energizes a laser (or other energy source) at each of the read/write heads **912** during write operations. The laser control circuitry conditions the signals to ensure the lasers provide sufficient energy to heat a spot on the disk **910** as it is being recorded. Other signals sent to or received from the read/write head **912** may also be conditioned via the preamplifier, such as heater control signals, sensor signals, etc. For example, a clearance control module **917** may read sensor data from the read/write heads **912** (e.g., SAGC, thermal sensor data) to determine current clearance, and modify a signal applied to a heater of the read/write heads **912** to adjust the clearance accordingly.

A gamma calibration module **928** may perform data collection and testing as described above as part of a calibration/testing functionality **930**. For example, the gamma calibration module **928** may cause test data to be written to various regions of the disk **910**. During the writing, servo ACG may be read to determine a change in reader clearance. After the writing of the same test data or different test data, the test data may be traversed by the reader and signal amplitude measured and recorded. Based on these tests, writer/NFT gamma can be determined and used by the apparatus **902**, e.g., by calibration/testing module **930** during factory calibration and qualification testing. The gamma may also be used derive clearance coefficients using the gamma, the clearance coefficients used to set read and write clearances during in-use drive operation. These clearance coefficients can be stored in persistent memory for use by firmware of the apparatus **902** during normal drive field operation.

The various embodiments described above may be implemented using circuitry and/or software modules that interact to provide particular results. One of skill in the computing arts can readily implement such described functionality, either at a modular level or as a whole, using knowledge generally known in the art. For example, the flowcharts illustrated herein may be used to create computer-readable instructions/code for execution by a processor. Such instructions may be stored on a non-transitory computer-readable medium and transferred to the processor for execution as is known in the art.

Unless otherwise indicated, all numbers expressing feature sizes, amounts, and physical properties used in the specification and claims are to be understood as being modified in all instances by the term "about." Accordingly, unless indicated to the contrary, the numerical parameters set forth in the foregoing specification and attached claims are approximations that can vary depending upon the desired properties sought to be obtained by those skilled in the art utilizing the teachings disclosed herein. The use of numerical ranges by endpoints includes all numbers within that range (e.g. **1** to **5** includes 1, 1.5, 2, 2.75, 3, 3.80, 4, and 5) and any range within that range.

The foregoing description of the example embodiments has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the embodiments to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. Any or all features of the disclosed embodiments can be applied individually or in any combination are not meant to be limiting, but purely illustrative. It is intended that the scope of the invention be limited not with this detailed description, but rather determined by the claims appended hereto.

What is claimed is:

1. A method, comprising:

determining a change in a reader clearance (dRdr) of a recording head during writing of a first test region based on a first function of servo active gain control;

determining a change in a writer clearance (dWtr) of the recording head during writing of a second test region as a second function of amplitude of the second test region, the amplitude being read after the second region is written;

determining a gamma value of the recording head as a ratio of dRdr and dWtr; and

using the gamma value to estimate differences between a reader motion and a writer motion during a calibration routine.

2. The method of claim 1, wherein the first and second test regions are the same region.

3. The method of claim 2, wherein the same region comprises at least part of a track.

4. The method of claim 1, wherein writing the second test region comprises writing a 2T signal.

5. The method of claim 1, further comprising determining, for a plurality of target clearances, a reader clearance distance as a third function of the servo active gain control, wherein determining dRdr comprises applying values of the servo active gain control to the third function.

6. The method of claim 1, further comprising determining, for a plurality of target clearances, writer clearance distance as a fourth function of the amplitude, wherein determining dWtr comprises applying values of the amplitude to the fourth function.

7. The method of claim 1, wherein the recording head comprises a heat-assisted magnetic recording head, and wherein the dWtr comprises a change due to heat generated by a write coil and optical components of the recording head.

8. The method of claim 1, further comprising deriving clearance coefficients using the gamma, the clearance coefficients used to set read and write clearances during in-use drive operations.

9. An apparatus comprising:

interface circuitry configured to send and receive signals to a recording head that reads from and writes to a magnetic recording medium; and

a controller coupled to the interface circuitry and configured to:

determine a change in a reader clearance (dRdr) of the recording head during writing of a first test region to the magnetic recording medium based on a first function of servo active gain control;

determine a change in a writer clearance (dWtr) of the recording head during writing of a second test region to the magnetic recording medium as a second function of amplitude of the second test region, the amplitude being read after the second region is written;

determine a gamma value of the recording head as a ratio of dRdr and dWtr; and

use the gamma value to estimate differences between a reader motion and a writer motion during a calibration routine.

10. The apparatus of claim 9, wherein the first and second test regions are the same region.

11. The apparatus of claim 10, wherein the same region comprises at least part of a track.

12. The apparatus of claim 9, wherein writing the second test region comprises writing a 2T signal.

13. The apparatus of claim 9, wherein the controller is further configured to determine, for a plurality of target clearances, a reader clearance distance as a third function of the servo active gain control, wherein determining dRdr comprises applying values of the servo active gain control to the third function.

14. The apparatus of claim 9, wherein the controller is further configured to determine, writer clearance distance as a fourth function of the amplitude, wherein determining dWtr comprises applying values of the amplitude to the fourth function.

15. The apparatus of claim 9, wherein the recording head comprises a heat-assisted magnetic recording head, and wherein the dWtr comprises a change due to heat generated by a write coil and optical components of the recording head.

16. The apparatus of claim 9, wherein the controller is further configured to derive clearance coefficients using the gamma, the clearance coefficients used to set read and write clearances during in-use drive operations.

17. A method comprising:

determining a change in servo active gain control values from a beginning of a writing of a test region of a recording medium to an end of the writing of the test region, the servo active gain control values being read from servo marks by a read transducer of a recording head during the writing;

after writing of the test region, reading the test region by the read transducer to determine a change in recorded amplitude from the beginning to the end of the writing;

determining a gamma value of the recording head based on the change in servo active gain control values and the change in recorded amplitude; and

using the gamma value to estimate differences between a reader motion and a writer motion during a calibration routine.

18. The method of claim 17, further comprising:

determining a change in a clearance of the read transducer (dRdr) from the beginning to the end of the writing based on the change in servo active gain control values;

determining a change in a clearance of a write transducer (dWtr) of the recording head from the beginning to the end of the writing based on the change in the recorded amplitude; and

wherein the gamma value is based on a ratio of dRdr and dWtr.

19. The method of claim 17, wherein a writer of the recording head comprises optical components that are heated via a laser, thermal expansion of the optical components contributing to the gamma value.

20. The method of claim 17, wherein writing of the test region comprises writing a 2T signal to the test region.

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